SECTION 8

VIGOR DISCUSSION

This section describes the variations in growth parameters for individual species along an inundation gradient, as represented by decreasing relative elevation, for the individual species. Observations on changes in growth parameters from season to season are also noted, and water depth tolerance ranges for both clump and individual species are compared to water depth ranges reported in research literature.

INDIVIDUAL SPECIES

The following subsection discusses the changes in growth parameters over the increase in mean water level, as represented by the decrease in relative elevation. The influences of season and competition on growth parameters are discussed for each species as well.

Influence of Elevation

The goal of collecting data on the growth parameters of the six study species along an elevation gradient was to elucidate the response of each species to various levels of inundation. However, the ranges of elevation, along which the growth parameters were monitored, fell short of including the extremes of elevation at which each species survive. Instead, the vigor data gathered reflect only a portion of a normal tolerance curve for each species' growth parameters as they would naturally vary over an elevation gradient in a wetland.

The vigor study species that displayed a positive relationship between variations in growth parameters and increasing water depth occupy the rising portion of the normal tolerance curve representing the change in growth parameter values over a range of water depths (elevations), as shown in Figure 8-1 and Table 8-1.

Juncus ensifolius, *Scirpus cyperinus*, and *Scirpus acutus* had a significant relationship between two or more of their growth parameters and a change in elevation. Basal circumference, height, and inflorescence increased for these species with lower elevation and hence greater average water depth. This trend suggests that these species exhibit maximal growth in generally flooded conditions somewhere below the average pond water line

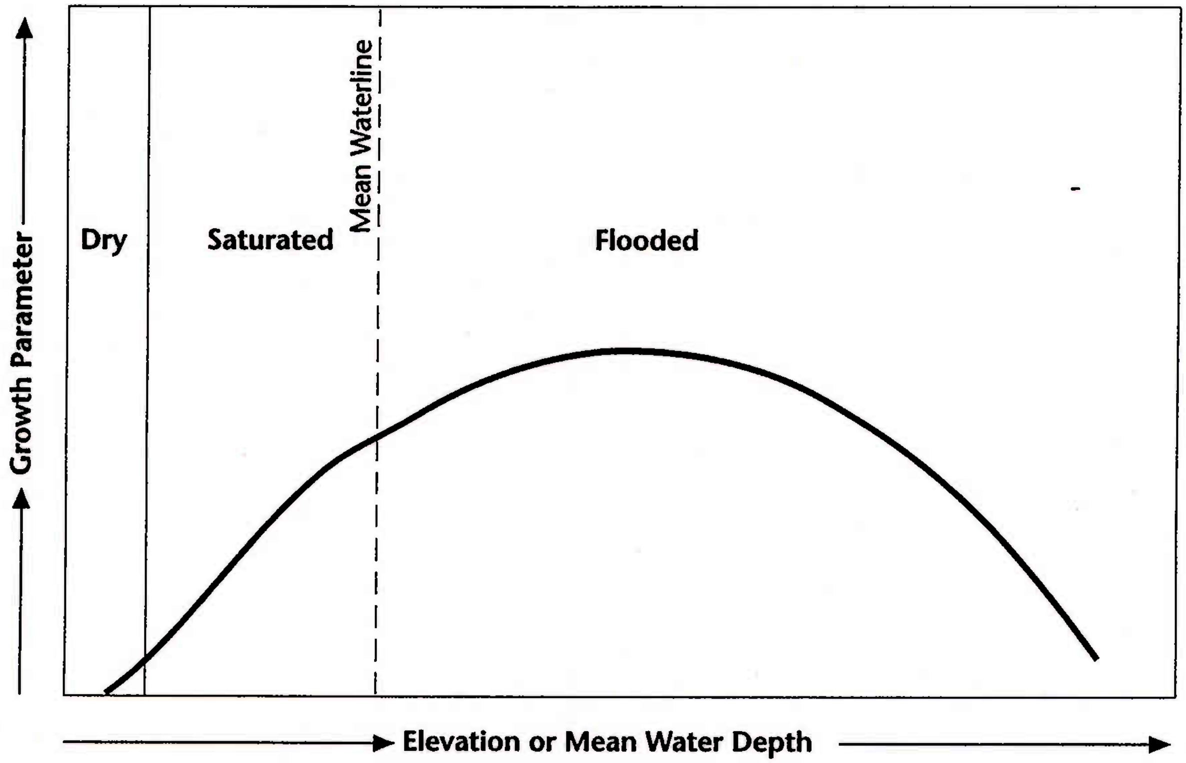

Figure 8-1. Relationship Between Growth Parameters and Elevation

TABLE 8-1. Significant Relationship of Growth Parameters with Elevation				
Species	Basal Circumference	Height	Number of Stems	Number of Inflorescences
Juncus ensifolius	yes	yes	indeterminate	yes
Scirpus cyperinus	yes	yes	not applicable	no
Scirpus acutus	not applicable	yes	not applicable	yes
Juncus effusus	no	yes	no	no
Scirpus microcarpus	no	no	no	no
Juncus tenuis	no	no	no	no

that occurred at the elevation of 1.59 feet (48.5 cm) in the South Base pond from July 1991 to August 1992.

Michaud and Richardson (1989) reported that *Scirpus cyperinus* prefers water depths of 0.05 to 0.3 m (0.2 to 0.98 ft). In the South Base pond study, *Scirpus cyperinus* was monitored along an elevation range of 0.22 feet above the mean pond level to 0.29 feet below the mean pond level. Lathwell et al. (1973) noted that the estimated maximum water depth tolerated by *Scirpus acutus* is less than 0.5 m (1.6 feet) to less than 1.0 m (3.3 feet). The range at which *Scirpus acutus* was studied in the pond ranged only from 0.14 feet above the mean pond level to 0.46 feet below. The optimal water depths for *Juncus ensifolius* were not found in the research literature; however, ranges of 10 cm (0.33 feet) above to 10 cm below the water line have been reported for *Juncus spp.* (Hammer 1992). Because the transitional (partially saturated to mostly flooded) zone in which *Scirpus cyperinus* and *Scirpus acutus* grew in the pond is far shallower than the optimal water depths, it would be expected that the growth parameters for these species would increase as each species spreads toward its preferred water depths.

Results for the other three species, *Juncus effusus, Juncus tenuis*, and *Scirpus microcarpus* were indeterminate. *Juncus effusus* varied significantly along the elevation gradient at each sampling event only in height, which, overall, was the growth parameter most dependent on elevation for all the individual study species. Michaud and Richardson (1989) indicated that the optimal water depth range for *Juncus effusus* is 0.15 m (0.49 ft) to 0.3 m (0.98 ft). Allen, et al. (1989) reported 15 cm (0.5 ft) above the water line to 15 cm below the water line as an optimal water depth range.

Hammer (1992), as mentioned previously, placed *Juncus spp.* from 10 cm above to 10 cm below the water line and also declared the range for *Scirpus spp.* to go from 10 cm (0.33 ft) above to 1 m (3.3 ft) below the water line. Considering the broad ranges above and below the water line at which *Juncus spp.* and *Scirpus spp.* can grow, it follows that measuring growth parameters for *Juncus tenuis, Juncus effusus*, and *Scirpus microcarpus* in a short transitional zone with a restricted range of water depths would yield an indeterminate relationship with elevation. This would especially be the case if the elevational range along which growth parameters were measured occurred within the range of optimal growth, where growth parameters vary the least according to elevation. Table 8-2 shows the individual species elevation and water depth ranges for the six species studied.

TABLE 8-2. Individual Species Elevation and Water Depth Ranges			
Species	Elevation Range (ft)	Water Depth Range	
		ft	cm
Juncus effusus	1.73 to 1.09	-0.14 to 0.50	-4.3 to 15.2
Juncus tenuis	1.85 to 1.12	-0.26 to 0.47	7.9 to 14.3
Juncus ensifolius	1.60 to 1.31	-0.01 to 0.28	-0.3 to 8.5
Scirpus acutus	1.73 to 1.13	-0.14 to 0.46	-4.3 to 14
Scirpus cyperinus	1.81 to 1.30	-0.22 to 0.29	-6.7 to 8.8
Scirpus microcarpus	1.81 to 1.17	-0.22 to 0.42	-6.7 to 12.8

Other Influences

The success of an individual plant, as defined by the increase in growth parameters, and how that success varies within a species over a certain area in a wetland, is influenced primarily by the prevailing hydrologic conditions in that wetland. These hydrologic conditions include weather, topography, and geology. However, other factors contribute to delineating the unique niche each species occupies in each wetland.

Competition between species and within a species can affect growth parameters variably, according to the parameter measured. It would be expected that growth parameters monitored during the pond study (basal circumference, stem number, height, and inflorescence number) would all respond to increased competition for space with a reduction in each parameter. This may have been the case with stem number and basal circumference, two strongly linked growth parameters, which would be expected to decrease with increased competition from neighbors. The gradual weakening of the relationship between the change in basal circumference and the change in elevation, according to regression and ANOVA significance values, for *Juncus ensifolius* may have resulted from the effects of competition.

In contrast, height might be expected to increase, to a point, with competition restricting lateral growth. *Juncus ensifolius* and *Scirpus acutus* variation in height over change in elevation tended to strengthen over the study, as reflected in regression and ANOVA significance values. The influence of competition on number of inflorescences may be more indirect, reliant on stem number and competition for nutrients rather than space.

The seasonality of growth parameters may also have caused some of the fluctuations in regression and ANOVA significance values during the study. Height and inflorescence number is most influenced by season, especially with annuals. Both *Juncus ensifolius* and *Juncus tenuis* regression R^2 values for variation in height over change in elevation dropped in October 1991 and increased again in May of 1992. *Scirpus acutus*, *Scirpus cyperinus*, and *Juncus effusus* all fell in R^2 values in October, with a rise in the following May for number of inflorescences. Response of significant values for variation in stem number and basal circumference over the elevation gradient showed no uniform abatement in regression R^2 values in the fall, with a concomitant spring rise in R^2 values.

Another source of variation in the study species growth parameters may be the recent introduction of the study species to the experimental site in spring of 1991. Differences in growth parameters between plants growing at different elevations may not become evident, statistically, until the plants reach a certain stage of maturity. For example, the relationship between *Juncus effusus* variation in number of stems and inflorescences over change in elevation notably increased in the significance of its R^2 and significant F values over the study period, and in the case of stems, rose to a value in May 1992 that indicated a valid relationship between the increase in stem number and a decrease in elevation. Although the relationship between variation in basal circumference and elevation for *Juncus effusus* never reached significance over the study. R^2 and significant F values increased. Similarly, *Scirpus acutus* variability in height became more strongly correlated with elevation difference over the study.

CLUMP SPECIES

The method of determining each clump species' tolerance to extremes in hydrologic conditions was simply to monitor the changes in elevation of the edges of each clump. Despite the simplicity of this method, the results from the pond study closely matched those found in the research literature. At the pond, *Typha latifolia* grew from 0.71 ft (21.6 cm) above to 2.09 ft (63.7 cm) below the mean pond water level. Hammer (1992) gave a similar range of 10 cm (0.33 ft) above to 70 cm (2.3 ft) below the water line. Hammer also mentioned that *Iris pseudacorus* spread to depths of 15 cm (0.5 ft). At the South Base pond, *Iris pseudacorus* grew at 0.38 ft (11.6 cm) above to 0.79 ft (24 cm) below the mean pond water level.

Michaud and Richardson (1989) placed *Sparganium americanum* in 0.3 m (0.98 ft) to 1.2 m (4 ft) of water. *Sparganium sp.* in the South Base pond fell within this range and extended into drier areas, ranging from 0.28 ft (8.5 cm) above the mean pond water line to 2.09 ft (63.7 cm) below. *Eleocharis ovata* was not mentioned in the research literature reviewed, but grew between 0.55 ft (16.8 cm) above and 1.09 ft (33.2 cm) below the mean water line at the pond.

SECTION 9

RECOMMENDATIONS

This section contains recommendations for the planning, construction, and maintenance of wetlands for stormwater pollutant remediation. These recommendations are based on the results of the South Base pond project and a review of related research literature.

POLLUTANT UPTAKE RECOMMENDATIONS

Rated solely on the quantity of lead, zinc, and petroleum hydrocarbons stored in plant tissue per unit area of biomass, *Typha latifolia* is the most desirable emergent for stormwater treatment in an artificial wetland. Although cultivating a monotypic stand of *Typha latifolia* may produce significant pollutant uptake, an artificial wetland constructed for stormwater treatment should integrate pollutant uptake with ecological diversity.

The other four study species, *Scirpus acutus*, *Iris pseudacorus*, *Sparganium sp.*, and *Eleocharis ovata*, all showed a capacity to store lead, zinc, and TPH in their tissues. These species should be included along with a variety of other wetland plant species in planning and constructing an ecologically viable artificial wetland.

The following data resulting from the pond study can be applied when designing an artificial wetland that provides effective pollutant uptake and supports ecological diversity:

1. ***Plant Typha latifolia Near Inflows.*** *Typha latifolia* should be encouraged to grow near the inflows, circumscribing the inflow forebay. The high pollutant uptake potential of *Typha latifolia* is best utilized near the pollution source, where its dense growth can also dissipate inflow energy, trap sediments, and support pollutant-oxidizing soil microbes in its rhizosphere.

2. ***Manage the Growth of Typha latifolia.*** *Typha latifolia* can easily dominate a newly constructed wetland and must be closely managed to prevent exclusion of other plant species. It grows and spreads quickly into recently disturbed sites with standing water, forming tall, dense stands that shade out and exclude other emergents. Therefore, *Typha latifolia* should be restricted

to areas near the inflow forebay (Figure 9-1) by regular thinning and harvesting of immature fruits.

3. ***Use Sparganium sp. for Metal Uptake.*** Although *Sparganium sp.* produces less biomass per unit area than *Typha latifolia*, it had the highest pollutant loadings per unit weight of tissue for lead and zinc and second highest loadings for TPH. The pollutant uptake potential of *Sparganium sp.* can be employed in the deeper areas of the inflow forebay, below *Typha latifolia*, for metal uptake (Figure 9-2). *Sparganium sp.* tolerates a broad range of water depths and can also be grown in flooded areas between the inflow and outflow, mixed with other emergents (Figure 9-1).

4. ***Use Scirpus acutus in Deep Areas.*** *Scirpus acutus* is a striking dark green emergent that thrives in water depths up to one meter and can be planted in the deepest parts of the inflow forebay and outflow (Figures 9-1 and 9-2). *Scirpus acutus* showed promising uptake potential in its root tissues for TPH, accumulating the third highest concentrations per unit area of biomass.

5. ***Plant Eleocharis ovata on the Wetland Edges.*** *Eleocharis ovata* grows in shallow water and saturated soils and could be planted toward the edges of the wetland. *Eleocharis ovata* was a significant accumulator of lead and zinc. It had the second highest loadings per unit weight of tissue after *Sparganium sp.*

6. ***Plant Iris pseudacorus on the Wetland Edges.*** *Iris pseudacorus* grows in narrow zones along the edges of wetlands and creeks where the transition in water depth is sharp. Besides being an attractive plant with spectacular flowers, *Iris pseudacorus* accumulates high concentrations of TPH in its root/rhizomes, second highest after *Typha latifolia* per unit area of biomass. *Iris pseudacorus* can be planted above *Typha latifolia*, at the edge of the inflow forebay and around the outflow as shown in Figures 9-1 and 9-2.

7. ***Use a Variety of Species.*** Emergent species with minimal pollutant uptake capacities should not be discounted. Many species of emergents foster conditions favorable to the proliferation of soil microbes in their root zones, which metabolize petroleum hydrocarbons and detoxify heavy metals.

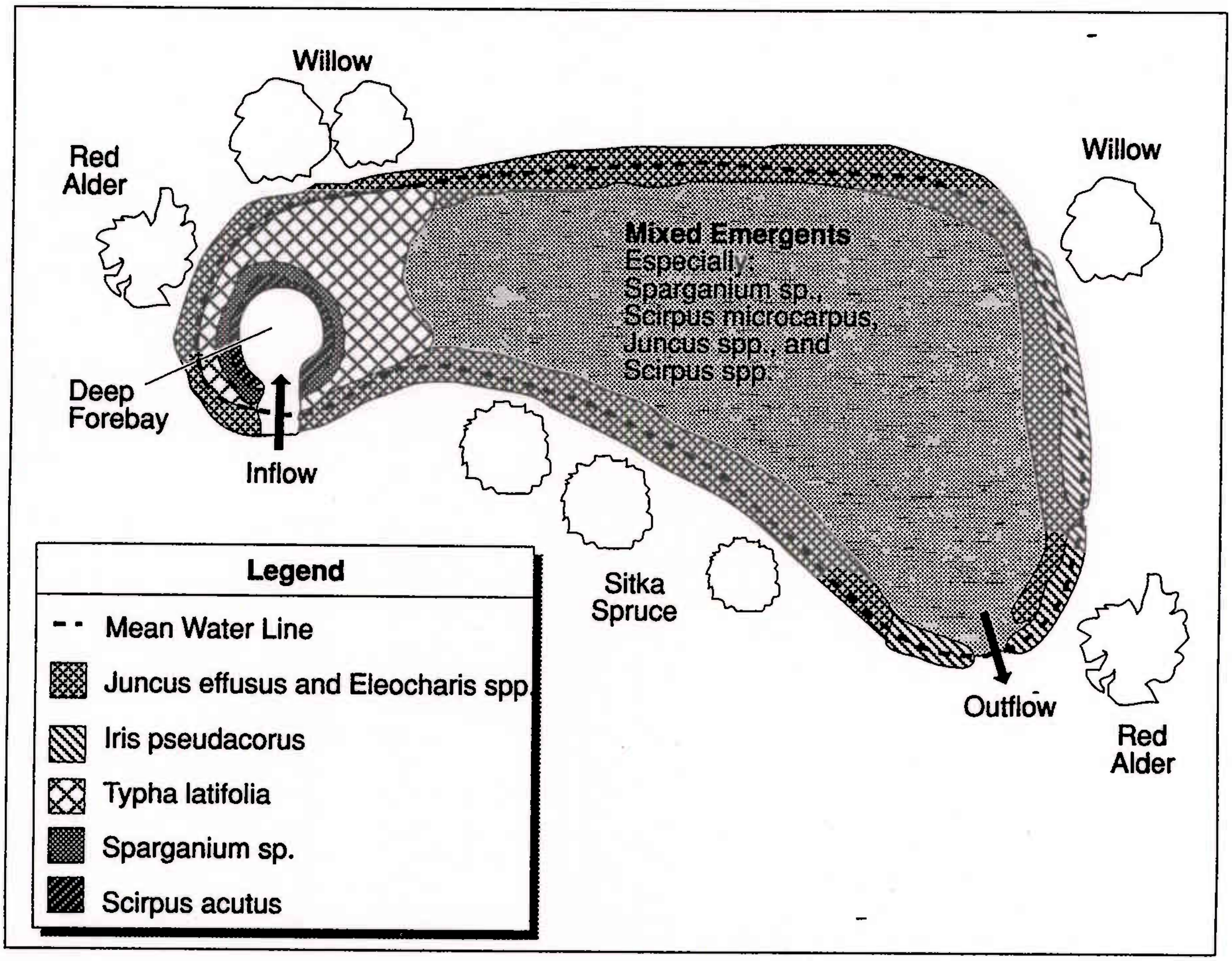

Figure 9-1. Suggested Placement of Wetland Emergents

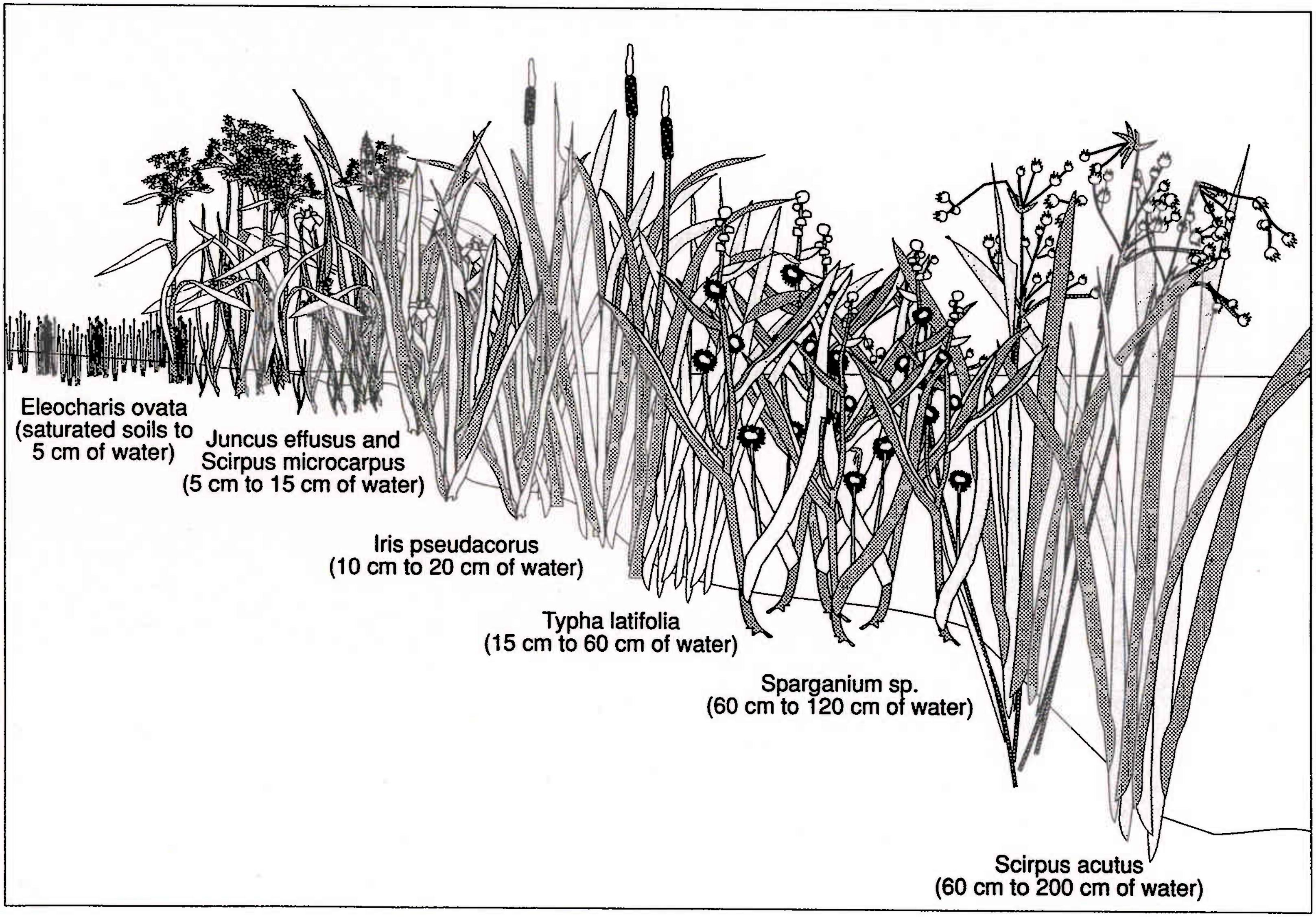

Figure 9-2. Suggested Placement of Wetland Emergents According to Water Depth

VIGOR RECOMMENDATIONS

Although the pond study of "individual" and "clump" wetland plant species for preferred inundation levels revealed only general trends, the trends discovered in plant vigor along an elevation gradient strongly suggest that most emergent wetland plants thrive in persistently flooded, shallow conditions. To maximize the pollutant removal benefits of the emergents, the following structural design considerations should be addressed when planning and constructing a wetland for stormwater treatment.

1. ***Topography.*** A broad, gentle slope into the wetland creates a greater area in which emergents can thrive, allowing greater pollutant uptake. A steep grade exposes plants to more variable water levels and erosion, restricts them to narrow zones, and encourages flow that limits sedimentation, resulting in minimal pollutant removal.

2. ***Hydrology.*** Wetland emergents require a fairly consistent water level. Stormwater inflow is sporadic and often intense and results in dramatic changes in water level. Emergent wetland plants can tolerate only moderate shifts in water depth with occasional seasonal flooding. Widely varying water levels can induce selective pressure on wetland plants and limit the range in which they survive. A pre-settlement basin preceding the wetland or a deep forebay within the wetland to receive inflow, combined with regulated outflows that extend hydraulic retention time, would moderate water level fluctuations.

Other important trends in plant vigor less directly related to inundation level were discovered in the pond study. The seasonal growth patterns of *Juncus spp.* and *Scirpus spp.*, as well as all wetland plant species, must be considered when planning the distribution of plant species within the wetland. In the Puget Sound region, the period of greatest pollutant input (the fall/winter rainy season) occurs when pollutant uptake activity is lowest, when the majority of plants are senescent or dormant. This has several ramifications for planning artificial wetlands receiving stormwater.

1. ***Use Plants with Long Growing Seasons.*** Choose perennial emergents or annuals with long growing seasons to maximize the period of pollutant uptake. Annual species should be placed in areas of low flow rate, where erosion is not a problem.

2. ***Use Rhizomatous Emergents.*** Rhizomatous emergents that grow back from root stocks are important for erosion control, sediment entrapment, and especially soil oxidation. Distribute them throughout the wetland, particularly near the inflows, where sedimentation and erosion are greatest.

3. ***Plant Perennial Species.*** Plant at least one perennial throughout the wetland to provide pollutant uptake and support pollutant-oxidizing soil microbes during the fall/winter rainy season. *Juncus effusus* is marginally dormant during the cool wet months, retaining green vegetation throughout the winter in the Puget Sound region. *Juncus effusus* also forms dense stands that facilitate sedimentation and control erosion, making it an ideal species to be cultivated near the inflows.

4. ***Do Not Use Artificial Wetlands as a Primary Treatment System.*** Unless runoff pollutant loadings are marginal, artificial wetlands, especially in the Puget Sound area, should not be used for primary treatment of stormwater. Accumulation of pollutants over the winter may severely hinder seed germination, overwhelm soil microbes, and damage tender new shoots from root stocks. Use oil/water separators, pre-settlement basins, and/or vegetated swales for pre-treatment of stormwater. Use artificial wetlands as a secondary treatment system, to remove dissolved solids and finer sediments that pass through primary treatment systems.

5. ***Control the Source of Pollutants.*** Source control of pollutants should be a year-round priority, with extra vigilance during the rainy season. Spills and leaks of fuels and oils are difficult to contain on wet pavement, quickly washing into storm drains.

6. ***Use Floating Booms to Trap Oil.*** Install floating booms made with oil adsorbing materials near the inflows and outflow to prevent floating sheens of oils and other materials from passing into the receiving waters. This is most necessary in the winter, when flow is the greatest and little vegetation exists to break up surface sheens before they exit the outflow.

7. ***Create a Deep Forebay.*** A deep forebay located at the inflow lessens the impact of stormwater volumes and pollutant loads on the wetland during winter dormancy by moderating inflow energy and facilitating sedimentation. A deep forebay also

provides overwintering refuge for wetland fish and invertebrates. Access to the forebay should be available for equipment to occasionally dredge and remove sediment accumulations.

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